



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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REPLY TO
ATTN OF: GP/43038

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for
Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,474,357

Government or
Corporate Employee : California Institute of Technology
Pasadena, California 91109

Supplementary Corporate
Source (if applicable) : JPL, Pasadena, California 91109

NASA Patent Case No. : XNP-09775

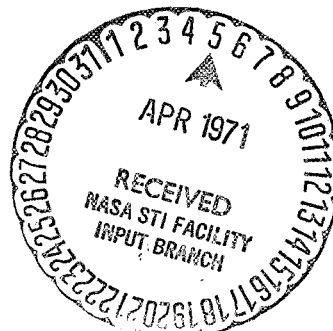
NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes ☒ No ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Dorothy J. Jackson
Dorothy J. Jackson
Enclosure

Copy of Patent cited above



Oct. 21, 1969

JAMES E. WEBB
ADMINISTRATOR OF THE NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION
TRANSMISSION LINE THERMAL SHORT
Filed Sept. 15, 1967

3,474,357

N71-20445 40%

MICROWAVE
SIGNALS

FIG. 1

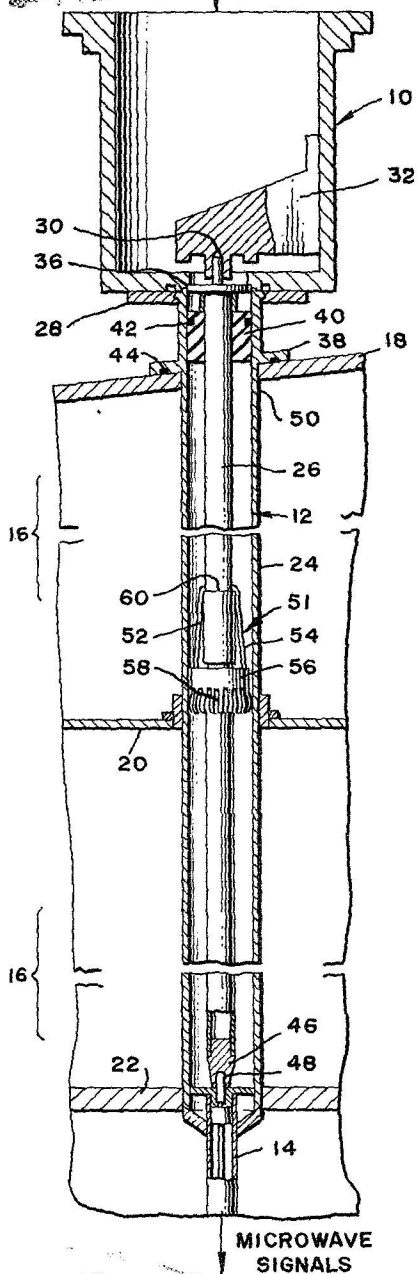


FIG. 2

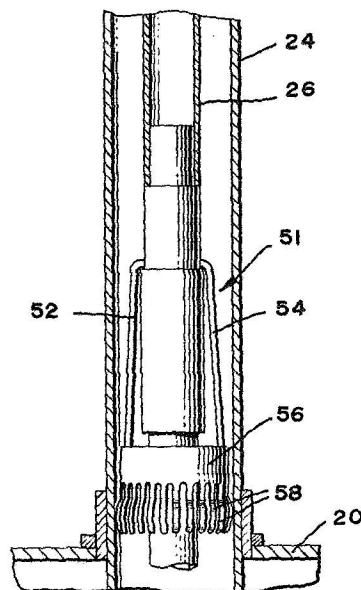


FIG. 3

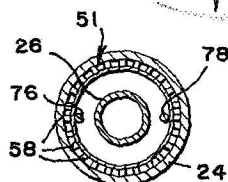
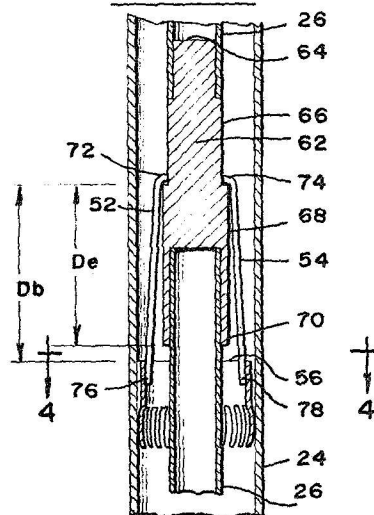


FIG. 4

ROBERT C. CLAUSS
INVENTOR

BY *9th St. Co.*
DE Leslie

ATTORNEYS

FACILITY FORM 602

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(CATEGORY)

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3,474,357

TRANSMISSION LINE THERMAL SHORT

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Robert C. Clauss, La Crescenta, Calif.

Filed Sept. 15, 1967, Ser. No. 668,247

Int. Cl. H01p 3/06

U.S. Cl. 333—96

18 Claims

ABSTRACT OF THE DISCLOSURE

A device for cooling the center or inner conductor of a coaxial cable by conducting heat between the outer and center conductors without substantial change in electrical characteristics, comprising bars or wires extending a quarter wavelength along the cable with one end fixed to the center conductor and the other end in contact with the outer conductor, and including a center conductor having a slightly increased diameter along the length of the bars.

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

This invention relates to electromagnetic wave transmission devices and more particularly to means for cooling components thereof.

The detection of very low level signals is often accomplished with amplifiers that must be cooled to very low temperatures. For example, communication with space probes at distances of millions of miles has been accomplished by feeding the signal from an antenna to a traveling wave maser operated at a temperature of 4.4° K. The maser amplifier and its refrigerator are mounted on a movable antenna structure, and both therefore must be compact and light weight. Additionally, such antennas are often situated at remote locations to decrease interference, and repair and replacement of parts must be as simple as possible.

The signals received by a tracking station antenna are typically directed to a waveguide horn and carried by a waveguide to the maser amplifier. The frequency used, such as 2.3 K. mHz. necessitates a relatively large waveguide, such as several inches in width. To extend such a waveguide to the cryogenically cooled maser amplifier would result in very large thermal paths and require excessively large refrigeration apparatus. Accordingly, at the entrance to the maser refrigeration apparatus, the waveguide is connected to a coaxial cable which conducts a signal to the maser. The coaxial cable allows a relatively small line to be used; however, due to resistive losses, it adds substantial noise. Furthermore, the coaxial cable conducts heat to the maser and adds considerable refrigeration load. The refrigeration which is required would be inefficiently utilized if all cooling were applied from the 4.4° K. refrigeration point at the maser apparatus.

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Both the noise contributed by the coaxial cable and the refrigeration load can be reduced by cooling the coaxial cable along its center portion to a temperature in between ambient temperature (nominally 290° K.) and the maser operating temperature of 4.4° K. The outer conductor of the cable is cooled by applying a refrigeration stage which is at a moderately low temperature, directly to the outer conductor. However, considerable difficulty is encountered in cooling the inner or center conductor, since it is electrically insulated from the outer conductor. Inasmuch as materials which are good thermal conductors are also generally good electrical conductors, the direct connection of a good thermal conductor such as a metal between the inner and outer conductors would result in an electrical connection between them. This would result in a high voltage standing wave ratio (VSWR). A high VSWR would prevent some signal power from reaching the maser amplifier, thereby decreasing signal-to-noise ratio. This invention provides a means for conducting heat from the coaxial cable center conductor to the outer conductor with a minimum increase in VSWR over a considerable bandwidth, and without appreciably changing the impedance of the coaxial line, thereby enabling cooling of a line at a center portion thereof to decrease noise and decrease the 4.4° K. refrigeration load.

SUMMARY OF THE INVENTION

The present invention provides a thermal short circuit between the outer and center conductors of a coaxial transmission line without substantial deleterious effects, by introducing conductive bars or wires between the center and outer conductors. The bars extend approximately a quarter wavelength along the length of the coaxial cable, and have one end in contact with the outer conductor. In addition, the center conductor is provided with a portion of slightly greater diameter, extending along most of the length of the wires. The conductive bars are of a material which normally conducts both heat and electricity. In the present invention, heat is conducted from the center coaxial conductor through the bars to the outer conductor. However, the microwave signal power is not shorted at this point because the conductive bars extend approximately a quarter wavelength before contacting the outer conductor, and the VSWR has only a small increase. An enlarged portion of the center conductor serves to maintain the proper impedance characteristics of the coaxial line so that there is a good match between it and the waveguide output and maser input to which it is connected.

In the particular embodiment of the invention illustrated herein, the conductive bars are soldered to the center conductor and make thermal contact with the outer conductor through contact fingers. The contact fingers are formed in a thin cylinder of metal having a diameter slightly smaller than the inner diameter of the outer coaxial conductor, thereby assuring large areas of contact. The thermal short circuit of the invention does not increase the bulk of the coaxial line. The center conductor of the coaxial line can be removed and replaced in a simple manner, thereby facilitating both initial assembly and replacement in the field.

A more complete understanding of the invention can be had by considering the following detailed description

of a preferred embodiment, the claims, and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a side sectional view of a portion of an amplifier system employing the invention;

FIGURE 2 is a partially sectional side elevation view of the invention;

FIGURE 3 is a sectional view of the invention; and

FIGURE 4 is a view taken on the section 4—4 of FIGURE 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGURE 1 illustrates a portion of the input line to a traveling wave maser for amplifying very low level microwave signals. The signals are initially received through a waveguide 10 which is connected to a feed horn of an antenna directed at the signal source, which may be a transmitter on a distant space probe. The signals, which are generally very weak, pass through a coaxial cable 12, or coaxial transmission line, to the input 14 of a traveling wave maser amplifier. The coaxial cable 12 is located in a refrigerator structure 16 which has a protective and insulating housing 18 around it, and which maintains a vacuum within the housing to provide insulation. The refrigerator structure has several refrigeration stations within it. A first, which maintains a moderately low temperature such as 80° K., is attached to first refrigeration plate 20. A final station, which maintains a temperature close to absolute zero, such as 4.4° K., is connected to final refrigeration plate 22. The final refrigeration plate 22 contacts the maser, which normally operates at temperatures below 4.5° K.

The coaxial line 12 has an outer conductor 24 and an inner or center conductor 26 for carrying the microwaves from the waveguide to the maser. The outer conductor 24 of the coaxial line is connected to the waveguide 10 by a holding flange 28. The center conductor 26 is connected to the waveguide by a center pin or "bullet" 30 which is inserted into a receiving hole in a waveguide to coaxial line transition 32, which extends between the walls of the waveguide and its center. A Teflon washer 36 helps to separate the center and outer coaxial conductors and maintain alignment. A flange 38 on the outer conductor 24 provides a firm attachment of the coaxial line to the refrigerator housing 18 and seals the covering around the hole through which the coaxial line enters.

The inside of the refrigerator structure 16 is maintained at a vacuum to reduce heat transfer. A vacuum seal 40 between the center and outer conductors of the coaxial line seals the line, so that the space between the center and outer conductors is maintained at a vacuum. O-ring 42 on the vacuum seal and O-ring 44 on the flange 38 help to maintain the vacuum seals.

At the end of the coaxial cable 12 which connects to the maser input 14, connections are provided by a tapered end portion 46 of the center conductor, having a split sleeve which receives a pin 48 of one of the maser input lines 14 which is a tubular copper coaxial line. The outer conductor 24 of the coaxial line is physically connected to the final refrigeration plate 22, which is connected to the maser.

Thermal insulation between the waveguide 10, which is at ambient temperature, and the near absolute zero temperature of the final refrigeration plate 22 is accomplished by the insulating properties of the vacuum within the refrigerator structure 16, and by constructing the center and outer conductors 26 and 24 of the coaxial line of relatively poor thermally conducting material, such as stainless steel. In order to provide a low loss path for microwaves through the coaxial line 12, the inner surface of the outer conductor 24 and the outer surface of the inner conductor 26 are plated with copper; a gold

flash layer is deposited over the copper to prevent corrosion. Inasmuch as very high frequency waves pass through the coaxial line 12, the electrical currents flowing through the center and outer conductors have a very small skin depth (approximately 0.000050 inch at 2,300 mHz.) and a very thin layer of copper is sufficient. Inasmuch as the stainless steel tubing of the center and outer conductors is relatively thin and of relatively long length, the amount of heat leaked therethrough is very small.

It should be noted that the thermal gradients, or variations in temperature, along the center conductor 26 are not linear because the thermal conductivity of stainless steel and of copper varies as a function of temperature, the conductivity of stainless steel being lower at lower temperatures. As a result, the refrigeration load is reduced by cooling the center conductor 26 at the first refrigeration station 20, instead of only at the final station 22. Furthermore, refrigeration apparatus is more efficient when the cooling is not to an extremely low temperature, such as that of the final station 22, and the cooling at first station 20 reduces the load at the final station. In one device constructed according to the embodiment of FIGURE 1, the heat leak through the center portion of the coaxial line was reduced from 75 milliwatts to 25 milliwatts by the addition of a thermal short.

Although reduction of refrigeration load is helpful, an even more important benefit from cooling the center conductor at an intermediate point, in many cases, is reduction of microwave noise. Noise arises because of the high temperature of the coaxial line, and cooling the line over as much of its length as possible reduces this noise considerably. In the device constructed in accordance with FIGURE 1, noise generated in the cooled portion of coaxial line, between the thermal short and the maser input, was reduced to one-ninth its previous level by cooling the center conductor from approximately 290° K. to 80° K. near its beginning.

The present invention is directed primarily to the cooling of the inner or center conductor 26 of the coaxial line. The difficulty of cooling the center conductor is due to the fact that it must be electrically insulated from the outer conductor 24, at least insofar as it concerns microwave power being carried. The thermal conduction between the center and outer conductors occurs through shorting bars 52 and 54 and a cylinder 56 which extend between the center and outer conductors. The cylinder 56 has finger 58 which contact the outer conductor 24 at a point along its length which is adjacent to the first refrigerating plate 20. Placement of the fingers 58 adjacent to the first plate 20 reduces the resistance of the thermal path between the outer and center conductors. If the heat had to be transmitted through a considerable length of the outer conductor 24, less heat would be transmitted from the center conductor. As discussed above, an important reason for cooling the inner conductor 26 along its length is to increase its conductivity and reduce the amount of noise added by the coaxial line. This occurs between an area slightly above the point 60, where cooling begins, and the final refrigerator plate 22. As has been also mentioned, the cooling at the point 60 reduces the thermal conductivity of the center conductor between an area near that point and the final refrigerator plate 22 so that even less heat is transmitted to the final plate. The particular construction of the thermal short 51 is adapted to efficiently transmit heat from the center conductor to the first stage of refrigeration while providing a minimum of disruption in electrical transmission characteristics for the microwave frequency at which the coaxial line is to be used.

A better view of the thermal short 51 is provided in FIGURES 2 and 3. The thermal short is constructed with a conductor rod 62 having a plug-like end 64, a center portion 66, and an expanded portion 68 which includes a sleeve-like end 70. The conductor rod 62 is

preferably constructed out of a single piece of copper, to reduce the number of joints which might act as thermal insulators. The plug-like end 64 has an outer diameter approximately equal to the inner diameter of the conductor 26, and is soldered in place to provide mechanical strength and good heat transfer characteristics. The center portion 66 has a diameter equal to that of the center conductor 26. The expanded portion 68 has a diameter larger than the diameter of the center portion 66 by a closely controlled amount, and the axial extension D_e of the expanded portion is also closely controlled. A hole in the expanded portion 68 extending from the end 70 inwardly, has a diameter approximately equal to the outer diameter of the center conductor 26, and after the center conductor is inserted into the conductor rod 62, they are soldered together.

The cylinder 56 of the thermal short is constructed of a thin strip of finger stock formed into a cylindrical shape. The outer diameter of the cylinder is smaller than the inner diameter of the outer coaxial cable conductor 24, but the cylinder has expanding fingers which expand to the diameter of the outer conductor to assure good thermal contact therewith. The bars 52 and 54 are straight, except for their inner ends 72 and 74 which are curved to pass around the discontinuity between the center portion 66 and the expanded portion 68. The inner ends of the bars are joined to the center portions 66 of the conductor rod by soldering, while the outer ends 76 and 78 of the bars are soldered to the inside of the cylinder 56.

The distance D_b between the inner end 72 or 74 and the closest edge of the cylinder 56 is approximately equal to a quarter wavelength of the waves to be carried through the coaxial line. The effect of the bars 52 and 54 which electrically connect the center and outer conductors but extend approximately a quarter wavelength along the transmission line between them, is similar to that of a quarter wavelength stub. A stub is a short-circuited section of a coaxial line tied across the normal transmission line, which can be used to support a center conductor of a coaxial line, but which acts as an insulator, this being well known in the microwave art. A quarter wavelength stub could be used in place of the thermal short of the present invention; however, it would extend outside of the outer conductor and prevent the removal of the length of coaxial cable through the opening in the housing 18 of the refrigerator structure. It is important to provide for the facile removal of the coaxial cable inasmuch as leaks can develop in the vacuum seal 40, and these leaks can be most readily corrected by replacing the entire coaxial line. A coaxial line without any side projections can be readily inserted through the housing 18 in the refrigerator structure. The vacuum seal can also be replaced by replacement of only the center conductor. This can be readily done because the thermal short readily slides through the outer conductor 24.

The design of the thermal short is made to comply with the following conditions: The voltage standing wave ratio (VSWR) must be kept to a minimum, the impedance of the line must not be substantially affected, and heat transfer characteristics must be good. An increased VSWR results in power loss and decreased signal-to-noise ratio. A change in impedance results in mismatching between the coaxial line and the waveguide 10 or the maser input 14. In many types of installations, a 50 ohm line is utilized, and it is important to keep the impedance of the coaxial line at 50 ohms, to prevent losses due to mismatching. These requirements are important only for the bandwidth at which the transmission line is to be used, such as between 2.2 K. mHz. and 2.4 K. mHz. It might be expected that the length D_b of the shorting bars would be a quarter wavelength, but it has been found in practice that the length D_b should be slightly less than a quarter wavelength. For the configuration of a thermal short shown in the figures, a length D_b approximately 98% of a quarter wavelength of the center frequency of

the band of frequencies to be transmitted has been found to be most satisfactory.

The expanded portion 68 has been found to be desirable in reducing VSWR and preventing a change of impedance. A person skilled in the microwave art would probably expect that the shorting bars 52 and 54 would increase the capacitance between the center and outer conductors 26 and 24 and therefore a recessed portion, instead of an expanded portion, would be required, to correct for the increased capacitance. However, it has been found that an expanded portion such as that shown at 68, instead of a recessed portion is necessary. In the configuration of the thermal short shown in the figures, an expanded portion 68 having a diameter approximately 25% larger than the outer diameter of the center conductor 26 provides optimum results.

A thermal short has been constructed in accordance with the foregoing for a $\frac{7}{8}$ inch nominal outside diameter coaxial line with a 0.341 inch outer diameter center conductor. The center and outer conductors were constructed of thin wall stainless steel with the inner surface of the outer conductor and the outer surface of the center conductor copper plated to carry radio frequency currents, and including a thin gold plating over the copper to reduce corrosion. The conductor rod 62 was constructed of a solid cylinder of copper with a center portion 66 of 0.341 inch diameter, equal to the outer diameter of the center conductor 26, and an expanded portion 68 of 0.430 inch diameter. Shorting bars 52 and 54 of 0.079 inch diameter copper rods were used. For a frequency band of transmission of 2.2 K. mHz. to 2.4 K. mHz., wherein a quarter wavelength of the center frequency is approximately 1.28 inches, a distance D_b of 1.25 inches was found to be optimum. The cylinder 56 was constructed of a strip of beryllium copper finger stock of half inch width, formed in a circle and with the ends overlapped, spot welded, and soldered together. This design was utilized to obtain good impedance match with the waveguide and maser, low VSWR in the signal frequency range, and sufficient thermal conductivity to transfer approximately 400 milliwatts with a minimum temperature difference across the short. The particular dimensions of the thermal short were arrived at largely by experiment, by trying various dimensions and testing the characteristics of the resulting thermal short. The foregoing thermal short was found to provide an insertion loss of 0.011 D_b , a contribution to maser noise temperature when cooled to 80° K. of less than 0.1° K., and a measured VSWR of 1.05/1 at 2.3 K. mHz. The VSWR was less than 1.10/1 throughout a range of 2.75 K. mHz.

While particular embodiments of the invention have been illustrated and described, it should be understood that many modifications and variations may be resorted to by those skilled in the art, and the scope of the invention is limited only by a just interpretation of the following claims.

I claim:

1. A cooling device for use in combination with a transmission line having an inner electrical conductor, and an outer electrical conductor disposed about said inner conductor, said device comprising:

a thermally conductive body having a first end portion adapted to contact said inner conductor, a second end portion adapted to contact said outer conductor, and a middle portion extending between said first and second end portions adapted to extend primarily along the length of said transmission line.

2. A cooling device as defined in claim 1 including: means connected to said transmission line for delivering high frequency electromagnetic waves thereto within a predetermined band of wavelengths; and wherein

the extension of said middle portion of said thermally conductive body between said first end portion and

an area near said second end portion, along the length of said transmission line, is approximately equal to a quarter wavelength of the center wavelength of said predetermined band of wavelengths.

3. A cooling device as defined in claim 1 including:

a conductor rod adapted for connection in line with said inner conductor of said transmission line, and to extend along the length of said transmission line adjacent to said thermally conductive body, said conductor rod having an outer diameter greater than the outer diameter of said inner conductor.

4. A cooled electrical conductor comprising:

a transmission line having an inner electrical conductor and an outer electrical conductor disposed about said inner conductor;

conductor means having good thermal conductivity, including a first end portion in thermal contact with said inner conductor and a second end portion in thermal contact with said outer conductor, and a middle portion extending between said first and second end portions, said middle portion extending primarily along the length of said transmission line.

5. A cooled electrical conductor as defined in claim 4 including:

means connected to said transmission line for delivering high frequency electromagnetic waves thereto within a predetermined band of wavelengths; and wherein

the extension of said center portion of said conductor means between said first end and an area near said second end adjacent to said outer conductor, along the length of said transmission line, is approximately equal to a quarter wavelength of the center wavelength of said band of wavelengths.

6. A cooled electrical conductor as defined in claim 4 wherein:

said inner electrical conductor has a cylindrical exterior of predetermined outer diameter along a majority of its length, and has an enlarged inner conductor portion with a diameter larger than said predetermined outer diameter extending along the length of said transmission line for at least a portion of the extension along said transmission line of said thermal conductor means.

7. A cooled electrical conductor as defined in claim 6 wherein:

said enlarged inner conductor portion extends along a majority of the extension along said transmission line of said thermal conductor means.

8. A cooled electrical conductor as defined in claim 4 wherein:

said outer conductor has an inner surface of substantially circular cross section; and said second end of said conductor means comprises a thin walled cylinder having a multiplicity of fingers which are spring biased against the inner surface of said outer conductor.

9. A cooled electrical conductor as defined in claim 8 including:

means connected to said transmission line for delivering microwave signals thereto primarily within a limited band of frequencies about a predetermined wavelength; and wherein

the extension along the length of said transmission line of said thermal conductor means between said first end and the edge of said cylinder closet to said first end of said conductor means is approximately equal to a quarter wavelength of said predetermined wavelength.

10. A cooled electrical conductor as defined in claim 8 including:

means connected to said transmission line for carrying microwaves of a frequency within a predetermined frequency band, with a predetermined center frequency of predetermined wavelength; and wherein

said extension along said transmission line of said conductor means between said first end of said thermal conductor means and said edge of said cylinder closets to said first end is less than one quarter of said predetermined wavelength.

11. A cooled electrical conductor as defined in claim 4 including:

a refrigeration station disposed about said outer conductor and in thermal contact therewith at a predetermined area along the length of said transmission line; and wherein

said second end of said thermal conductor means is disposed against said outer conductor at an area adjacent to said refrigeration station.

12. A cooled electrical conductor as defined in claim 4 wherein:

said transmission line includes a first end portion surrounded by an environment at an ambient temperature normally greater than 270° K., a second end portion normally at a temperature no more than several degrees Kelvin above absolute zero, and an intermediate refrigeration station at a point between said first and second ends maintained at a temperature between the temperatures at said first and second ends; and wherein

said second end of said thermal conductor means is located adjacent to said intermediate refrigeration station.

13. In a coaxial line for carrying microwaves from a source which normally delivers microwaves within a predetermined limited band of frequencies, the improvement comprising:

shorting means of thermally conductive material extending between the inner and outer conductors of said coaxial line, and having a first end portion disposed adjacent to said inner conductor and a second end portion disposed adjacent to said outer conductor of said coaxial line;

means thermally connecting said first end portion of said shorting means to said inner conductor; and

means thermally connecting said second end portion of said shorting means to said outer conductor;

said shorting means extending along the length of said transmission line a distance approximately equal to a quarter wavelength of the central frequency of said band of frequencies.

14. The improvement in a coaxial transmission line as defined in claim 13 wherein:

said means thermally connecting said second end of said shorting means to said outer conductor comprises a cylinder disposed within said outer conductor, having a plurality of contact fingers in contact with the inner surface of said outer conductor.

15. The improvement in a transmission line as defined in claim 13 including:

an expanded portion means disposed about said inner conductor along a majority of the extension of said shorting means along the length of said transmission line, for enlarging the effective outer diameter of said inner conductor.

16. The improvement in a transmission line as defined in claim 15 wherein:

the ratio between the outer diameter of said expanded portion and the outer diameter of said inner conductor at areas other than said expanded portion is approximately one and one-quarter.

17. A thermal short for a coaxial transmission line having a central conductor and an outer conductor disposed about said central conductor, comprising:

a conductor rod having ends for thermal and electrical connection to said central conductor of said coaxial line and in line therewith, said conductor rod having an expanded portion with an outer diameter greater than the outer diameter of said central conductor;

a thin-walled cylinder having a plurality of contact fin-

gers for making thermal contact with the inner surface of said outer conductor of said coaxial line; and at least one shorting bar of thermally conductive material having a first end thermally and electrically connected to said conducting rod at an edge of said expanded portion and a second end thermally and electrically connected to the inside of said cylinder.

18. A thermal short as defined in claim 17 including: means connected to said transmission line for propagating microwaves approximately equal to a predetermined frequency; and wherein

the distance between said first end of said shorting bar and the edge of said cylinder closest to said first end

of said shorting bar is approximately equal to a quarter wavelength of the waves of said predetermined frequency while passing through said transmission line.

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H. K. SAALBACH, Primary Examiner

10 L. ALLAHUT, Assistant Examiner

U.S. Cl. X.R.

174—15; 333—99